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Contribution by Ernest I. Rich to paper on "Surveying the Earth and its
Environment from Space" for CPEMRC, August 26-30, 1974

Photogeologic Analysis of ERTS-1 Imagery, Northern California

The geomorphic, lithologic and structural interpretation of ERTS-1
imagery of northern California is consistent with the known geology but
suggests some local refinements to the lithologic and structural relations
in the region. The analysis suggests also that new structural data, per-
haps not fully appreciated heretofore, may be useful for mineral and min-
eral fuel prospecting.

Several geomorphic regimes, defined on the basis of drainage density,
texture and pattern and on the general topographic and lithologic charac-
teristics (figure 1), have been recognized. ERTS-detected linear features
(figure 2) have been grouped into several linear systems (figure 3) which
are important in the structural interpretation of northern California (Rich
and Steele, 1974).

Recent ideas concerning late Mesozoic and Cenozoic plate tectonics
suggest that the melange-style deformation within the Coast Range is re-
lated to a late Mesozoic subduction zone (Ernst, 1970). The relatively
little deformed coeval marine sedimentary rocks that crop out along the
western margin and unconformably underlie the Tertiary to Holocene rocks
in the central part of the Sacramento Valley are thought to have been de-
posited in an "arc-trench gap" between the Coast Range subduction zone
and the Sierran arc (Dickinson and Rich, 1972).

Within northern California economically important minerals are dis-

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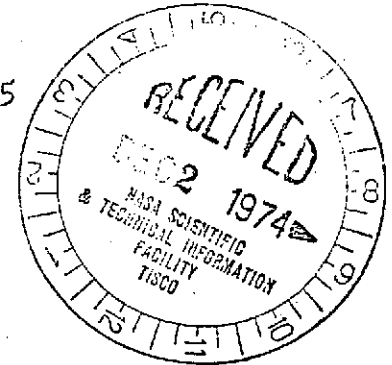
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74-155

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Lawrence J. Placencia

E. E. Baker
E. E. Baker
Deputy General Manager

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Geomorphic regime, figure 1); 2) copper, lead, zinc and gold deposits are associated with plutonism in the Sierran arc (Sierran geomorphic regime); and 3) mineral fuels are chiefly confined to the thick sedimentary rock sequence within the intervening arc-trench gap (Great Valley geomorphic regime).

The known deposits of mercury are associated with a northwest-trending linear system - San Andreas System on figure 3. Steeply dipping dikes or large nearly horizontal sheetlike bodies of serpentinite are commonly related to the San Andreas System of linears and these bodies are host rock for many of the mercury deposits. The east-northeast trending Valley System of linears (figure 3) which can be traced across the Coast Ranges, the Sacramento Valley and into the western foothills of the Sierras, overprints the San Andreas System. In the Coast Ranges, Pliocene to Holocene volcanic centers, geothermally important areas and hot springs are associated with some of the linear elements included within the Valley System. Economically productive mercury deposits (Mayacmus, Knoxville and Wilbur Springs districts) are at, or near, the points of intersection of the San Andreas and Valley Systems of linears.

Copper, lead, zinc, and gold deposits on the western slope of the Sierra Nevada are associated with the north-trending Sierran linear system (figure 3). Rich and Steele (1974) have suggested that this system may be older than, or at least penecontemporaneous with, the mid- to late-Mesozoic intrusions in the Sierras. Many of the deposits in the Sierra Nevada, however, are coincident with the intersections of the Sierran System and the east-trending Valley System of linears.

Most of the oil and gas fields in northern California underlie the alluviated part of the Sacramento Valley. The locations of some of these fields are closely related to the linear elements of the Valley System or

to the northwest-trending San Andreas System. Published subsurface data from a few of the wells suggest that some of the ERTS-detected linear elements in the alluvium of the Sacramento Valley can be correlated with faults in the subsurface.

In summary, the analysis of the ERTS-1 imagery has clearly demonstrated the value of satellite imagery in regional geomorphic and geologic reconnaissance and its potential usefulness for geologic interpretation and mineral prospecting.

REFERENCES CITED

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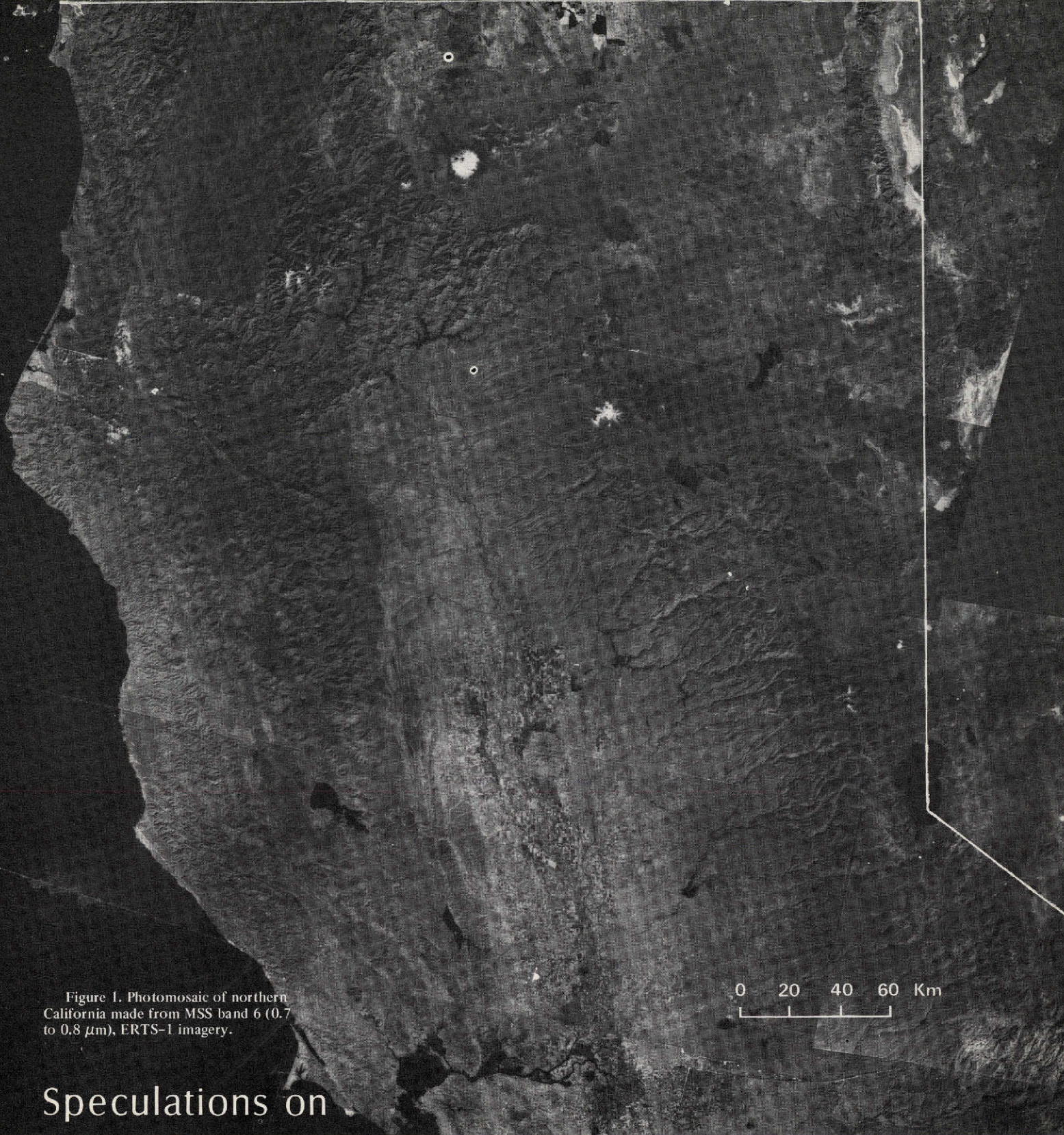


Figure 1. Photomosaic of northern California made from MSS band 6 (0.7 to 0.8 μm), ERTS-1 imagery.

0 20 40 60 Km

Speculations on

Geologic Structures in Northern California as Detected from ERTS-1 Satellite Imagery

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ABSTRACT

Repetitive multispectral ERTS-1 (Earth Resources Technical Satellite-1) imagery of northern California has disclosed several systems of linear features that may be important for the interpretation of the structural history of California. Four linear systems coexist within the northern Coast Ranges. They are separated from an orthogonal system of linear features in the Klamath Mountains

by a set of discontinuous east-southeast-trending linear features (the Mendocino system) which are traceable from the Pacific Coast at Cape Mendocino into the eastern foothills of the Sierra Nevada. Within the Sierra Nevada, the Mendocino system separates the north-trending Sierran system from a set characteristic of the Modoc Plateau.

With minor exception, little overlap exists among the systems, which suggests a decipherable chronology and evolutionary history for the region. The San Andreas system of linear features appears to truncate or coexist with most other systems in the northern Coast Ranges. The Mendocino system truncates the Klamath, Sierran, and Modoc systems. The Sierran system may represent fundamental and long-persisting early to mid-Mesozoic zones of crustal weakness which may have been reactivated during late Mesozoic time. The Mendocino system was possibly developed during mid- to late Mesozoic time, and recurrent movement has persisted into the Holocene Epoch. The Mendocino system is thus an important element in the structural framework of northern California.

INTRODUCTION

Regional studies using low-altitude aerial photography may be complicated by the large numbers of photos requiring examination and by the fact that large regional features may be masked by, or may form the background for, finer detailed features. ERTS-1 (Earth Resources Technical Satellite-1) imagery provides an accurate small-scale image of a large segment of the Earth's surface on which many of the finer detailed features are not well defined, and the regional characteristics thus are emphasized or are easier to detect. Repetitive multispectral ERTS imagery makes it possible to evaluate regional features at the most photographically advantageous times of the year with regard to vegetative cover, sun angle, and sun azimuth.

In this report, we present our preliminary analysis of ERTS-1 satellite imagery of northern California. Because of the uncertainty inherent in photo-geologic interpretation, there are bound to be differences with interpretations made for specific areas on the ground, but it is hoped that the data may prove helpful and encourage re-examination of current geologic interpretations in light of the data presented here.

Figure 1 is a small-scale uncontrolled mosaic of northern California prepared from ERTS imagery. Figure 2 is a diagrammatic sketch of the physiographic provinces included in Figure 1.

Figure 3 (black lines) is a compilation of the linear features whose positions were determined after an examination of about 200 individual images obtained

during repetitive passes of the satellite over northern California for the time period September 1972 to July 1973. From 6 to 20 images of any specific area were examined (the number of images per area being variable because of the percentage of cloud cover over the area during satellite orbits); hence the seasonal changes in sun azimuth and sun angle and the seasonal vegetational changes were considered and evaluated. The data from the images were compiled on a working map at a scale of 1:500,000 by projecting the original 70-mm positive transparencies, which were on a scale of 1:3.4 million, through a standard classroom 3¼- X 4¼-in. projector onto a translucent frosted-glass screen. The resolution of the imagery is about 300 ft (100 m).

LINEAR FEATURES

The features shown in black in Figure 3 include aligned streams or segments of streams, aligned offsets along several adjacent streams, aligned ends of consecutive ridge spurs, anomalous alignment of groups of topographic features (such as continuous straight ridge crests that are aligned with anomalously straight reaches of streams), aligned tributaries over rather long distances, aligned saddles in ridges, and other geomorphic features used in photogeologic work to indicate fracture, joint, or fault systems. Sharp linear tonal contrasts were included on the map as linear features if they could be identified on two or more sets of images taken at different times of the year. Linear features commonly associated with bedding in sedimentary rocks were excluded unless the bedding was offset or appeared to be truncated along a persistent linear zone. Only a few,

nearly horizontal, planar features such as thrust faults could be detected unless they separated rocks with gross lithologic differences (tonal and textural difference on the images) or the surface traces of the planar elements formed anomalous topographic features. Linear man-made features were carefully excluded.

Although the criteria used to define the linear features shown on the map are those commonly used to define fractures, joints, or faults from photographs, the geologic reason for most of the linear features observed on the ERTS images is not known. However, because of the care with which we examined each image, the features are assumed to be geologically controlled, and a geologic explanation for them should be investigated in the field.

The green lines in Figure 3 show the location of the faults in northern California that have been recorded on a new preliminary Geologic Map of California (used with permission of the California Division of Mines and Geology [1972]) and is included here for purposes of comparison. The high proportion of coincidence lends credence to the assumption that the linear features are geologically controlled. Other similarities or differences in the linear patterns become apparent when these two maps are compared.

We wish to point out some of the gross linear patterns and to suggest possible relations among the patterns. The patterns may be divided into several linear systems defined on the basis of their surface trends and their relation to adjacent systems. Some of the systems are parallel with the topographic grain of the area, and this relation has long been recognized. Other systems cut across the topographic grain or are oblique to it and have not been recognized or described.

LINEAR SYSTEMS

The linear pattern in the northern California Coast Ranges (Fig. 4) is particularly complex and differs from those in Klamath Mountains, Modoc Plateau, and Sierra Nevada physiographic provinces (Fig. 1); however, it is possible to subdivide the Coast Ranges pattern into distinct linear systems. Within the southern one-third of the Coast Ranges, extending from the latitude of San Francisco Bay to just north of Clear Lake and from the Pacific Coast to the western edge of the Sacramento Valley, four coexisting linear systems predominate (Fig. 3).

The San Andreas system is made up of northwest-trending linear features more or less parallel with the San Andreas fault zone; it includes the Hayward fault and several smaller linear features that trend subparallel to the San Andreas fault. On the basis of topographic expression and tonal contrast observed on

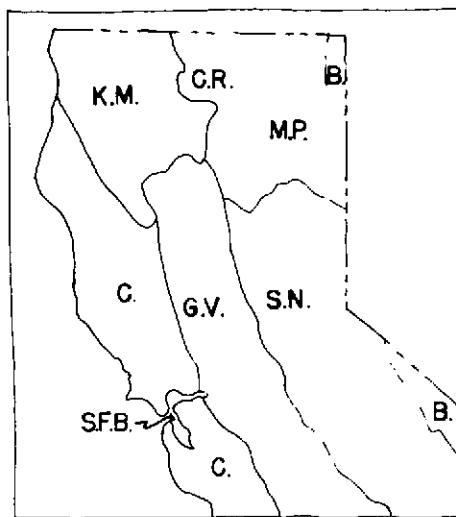
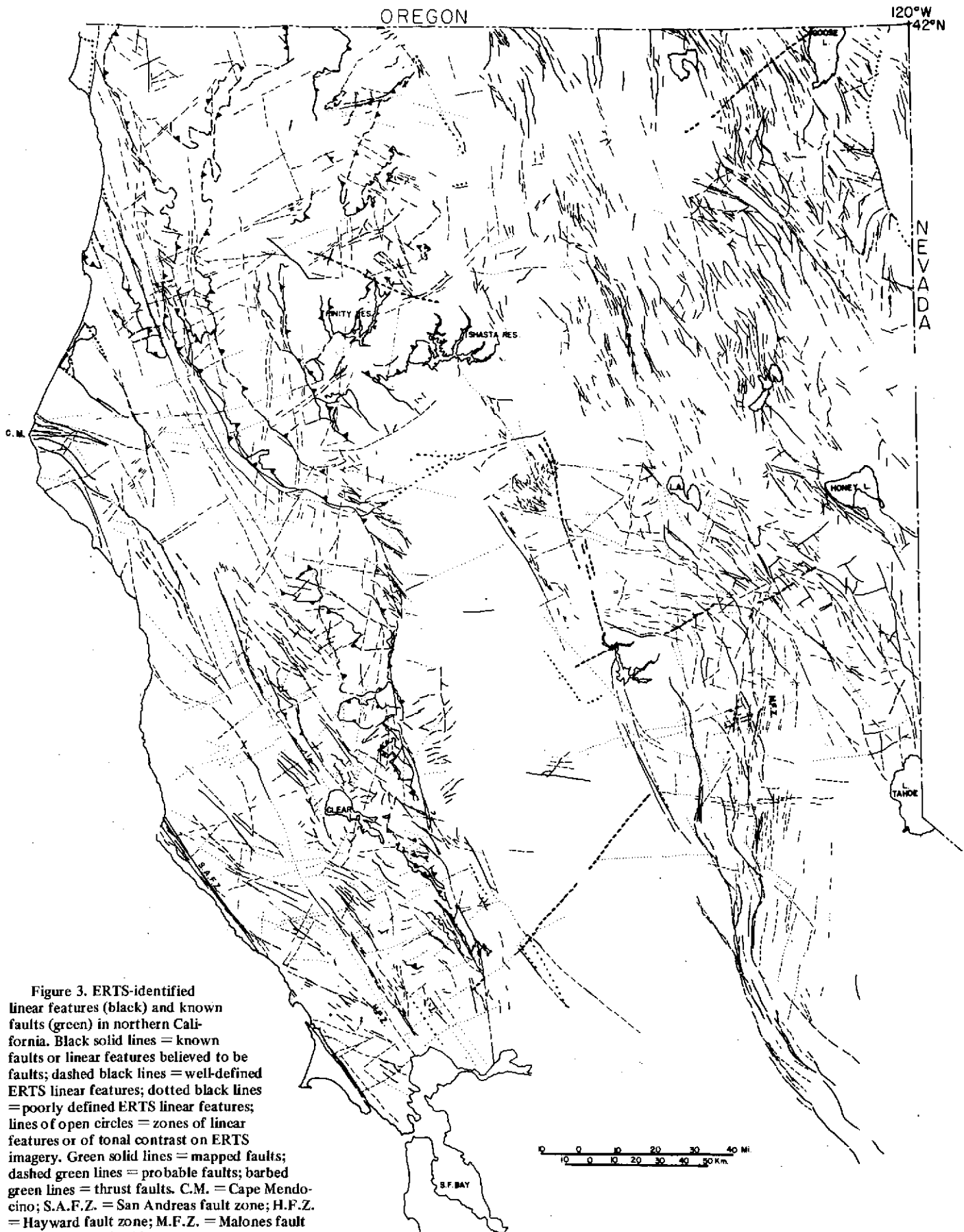


Figure 2. Physiographic provinces in northern California. K.M. = Klamath Mountains; C. = Coast Ranges; G.V. = Great Valley; C.R. = Cascade Ranges; M.P. = Modoc Plateau; S.N. = Sierra Nevada; B. = Basin and Range (from Thornbury, 1965); S.F.B. = San Francisco Bay.



the ERTS imagery, we suggest (Fig. 3) that the northern extension of the Hayward fault north from San Francisco Bay is farther west and extends farther north than has been previously recorded.

The Coastal system comprises a set of west-northwest-trending linear features confined primarily to rocks of the Coastal Belt Series between the San Andreas and Hayward faults (Figs. 1, 3). Individual linear features of the Coastal system do not extend west of the San Andreas fault zone and only a few extend east of the Hayward fault. The trends of these features are crudely parallel with the topographic grain of the area.

The Central system, made up of north-northeast-trending linear features, is confined to the central core of the Coast Range and involves rocks assigned to the Franciscan assemblage and Coastal Belt (Bailey and others, 1964). The trends of individual features within the Central system vary more than those in the systems described above, but they are nevertheless sufficiently distinct from the other systems to suggest a different set of geologic circumstances for their origins.

The Valley system, an east- or east-northeast-trending system of linear features, appears to crosscut all the other systems and locally extends from the Coast Ranges into and across the Sacramento Valley. The features included in the Valley system have not been previously recorded in the published literature available to us but have been described in unpublished reports (L. H. Lattman, 1973, personal commun.).

About 30 mi (48 km) north of the latitude of Clear Lake, linear features of the Coastal and Valley systems diminish in number and are replaced northward in the Coast Ranges by systems more closely associated with the Klamath Mountains or with a belt of metamorphic rocks associated with the Coast Range thrust fault (Bailey and others, 1970). The San Andreas system persists northward to Cape Mendocino, although it is less clearly defined north of the cape. The termination of the Coastal and Valley systems north of Clear Lake suggests a change in the underlying geologic structure. The fault map (Fig. 3) shows fewer known faults in this region, but this may be due to the lack of adequate detailed mapping in the area.

The east-southeast-trending discontinuous set of linear features, here referred to as the Mendocino system, is traceable from the Pacific Coast at Cape Mendocino, across the northern end of the Sacramento Valley and into the eastern foothill belt of the Sierra Nevada. Although individual linear features within the Mendocino system are discontinuous, the system as a whole represents a wide

belt that separates regions with distinctly different linear patterns. In the Coast Ranges, the region south of the Mendocino system consists of the San Andreas and Central systems; north of the Mendocino system, the region is dominated by an orthogonal set of linear features associated with the Klamath Mountains. In the Sierran foothills, the Mendocino system separates systems associated with the plutonic rocks of the Sierra Nevada from those associated with the late Tertiary volcanic rocks of the Modoc Plateau. The Mendocino system, therefore, may be significant in the interpretation of the structural framework of northern California.

Within the Klamath Mountains province, an orthogonal system of linear features, one set of which trends east-northeast and the other north or a few degrees west of north, is referred to as the Klamath system. It is bounded on the south by the Mendocino system and on the west by curvilinear features that, by comparison with Figure 3, are probably a series of thrust faults. cursory examination of the ERTS imagery suggests that the Klamath system extends northward into Oregon, but we have not noted a clearly defined northern limit. The Klamath system appears to terminate rather abruptly just east of Shasta Reservoir along a poorly defined north-trending zone where the orthogonal pattern of the Klamath system changes to one whose trend is predominantly north-northwest: the Modoc system of this report.

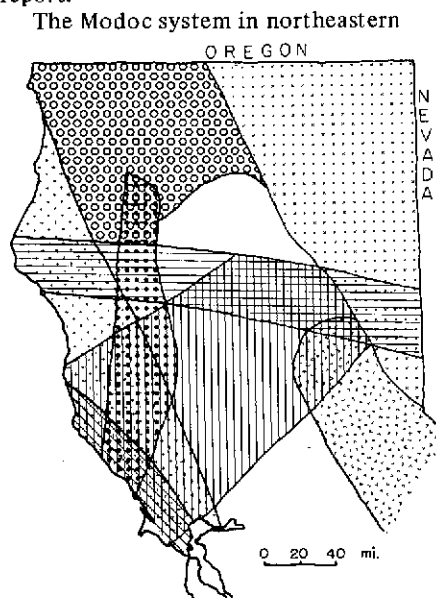


Figure 4. Location of linear systems. Interpretation of patterns: + = San Andreas system; NW-SE diagonal lines = Coastal system; black dots = Central system; horizontal lines = Mendocino system; open circles = Klamath system; x = Modoc system; v = Sierran system; vertical lines = Valley system. (Limits of systems are only approximate; see Fig. 3 for geographic extent.)

California includes some elements which have long been recognized (Hinds, 1952). This system, which extends from the vicinity of Lake Tahoe northward to Goose Lake and into Oregon (Fig. 3), consists of short, discontinuous features generally trending northwest, that grossly form an orderly pattern. A zone of features along the western margin of the system has a persistent north-northwest trend, but it is included here within the Modoc system because its trend more closely approximates the Modoc linear features than those of other systems in the area. Between Lake Tahoe and Honey Lake, along the eastern border of California (Fig. 3), a few linear features trend east-southeast subparallel with the Mendocino system. They may represent an eastward continuation of the Mendocino system.

The western slope of the Sierra Nevada, between Lake Tahoe and the eastern edge of the Sacramento Valley, is characterized by linear features whose trend is only a few degrees east of north; these are referred to as the Sierran system. The few east-trending features within the Sierran system may represent extensions of the Valley system from the Coast Ranges into the Sierra; however, only a few of them can be traced across the alluviated Sacramento Valley.

The Sierran system is truncated on the north by the Mendocino system, on the northeast by the Modoc system, and on the south and west by a fairly continuous set of features along the eastern margin of the Sacramento Valley (Malones fault zone?). The truncation of the Sierran system at the edge of the Sacramento Valley may be more apparent than real because it is difficult to detect and verify linear features within the alluviated part of the valley.

Other linear features shown in Figure 3 do not appear to be related to any of the above systems. For example, broad zones of short discontinuous features confined to, or associated with, subtle tonal changes on the ERTS imagery are depicted in Figure 3 by lines of small open circles. The most conspicuous of these zones trends northeast across the southern part of the Sacramento Valley. Other such zones are near the junction of the Mendocino and Modoc systems and in the vicinity of Goose Lake in northeastern California. Although these features may be subparallel with the Valley system, they are excluded from it because of their different photographic and topographic characteristics. The linear features bordering both the eastern and western margins of the Sacramento Valley are not included within any of the systems described here; they are subparallel with the western zone of the Modoc system, but they do not appear

to be geologically or topographically related to it.

DISCUSSION

Some of the individual linear features have been recognized for many years and are documented by published geologic maps (Fig. 4). Similarly, some of the linear systems have been recognized, but others have not. Speculation concerning the detailed relationship among the various linear systems is beyond the scope of this report, but some general observations concerning the regional relations and chronology can be made, based on the following assumptions:

The linear features are assumed to be geologically controlled; therefore, the linear systems reflect physical and geologic conditions that were in existence at the time of their development. The linear features which were field checked by us, or were previously known to us, either show fault displacement or are zones of intense fracturing or jointing. The similarity between the trends and locations of many ERTS-detected features and known faults (Fig. 3) strengthens the assumption that the linear features and linear systems are geologically controlled.

The linear features making up a linear system are assumed to have developed penecontemporaneously, and hence their original trend resulted from forces acting at the time of their formation. This does not preclude changes from the original trend by translation or rotation or later deformation along the pre-existing trend, but rather it assumes that once a system is formed, any regional change affects a system as a whole.

Further, we assume that one or more systems may be superimposed, but traces of the original system persist and are reflected, however subtly, in the geomorphic characteristics of the land surface. Clearly, the surface expression of a system may be obliterated by younger deposits such as lava flows or alluvial deposits; but we assume that surface erosion and later deformation (particularly along pre-existing trends) will not obliterate an older system on a regional scale—in some cases these processes may actually emphasize the surface characteristics. Trends of older linear systems have been detected in overlying sedimentary rocks and alluvium (such as the expression of the Valley and Mendocino systems through the Tertiary rocks and alluvium of the Sacramento Valley). The detectability, however, may be due to the localization of ground water along pre-existing fractures rather than to renewed crustal deformations or erosion.

Within the framework of the above description of the linear systems and the

assumptions made regarding them, some regional relations among the systems can be tentatively deduced. With the exception of the southern one-third of the Coast Ranges, most of the systems are separated from one another with only minor overlap. This suggests a decipherable chronologic and evolutionary development of the systems. For example, the Sierran and Klamath systems appear to terminate at their junction with the Mendocino system, and the Modoc system is overprinted by the Mendocino. These relations suggest that the Sierran and Klamath systems are relatively older than the Modoc system and that the Mendocino is the youngest of the four. Chronologic deductions like this may be weakened because of the uncertainty of the relative age of the Modoc system, whose trend may be inherited from an older fracture system beneath lava flows of late Tertiary to Holocene age which make up the surface rocks of the Modoc Plateau, or they may be contemporaneous with, or younger than, the flows. Also, deformation may have recurred through time along the trend of the Mendocino system, and the overprint on the Modoc system may merely represent the latest episode of movement. Although chronologic comparisons such as this may be invalid, the spatial relations among the four systems remain and require explanation.

The San Andreas system is pervasive in the northern Coast Ranges, and, except for the Klamath system, it appears to truncate or coexist with other systems. The Coastal system, for example, is confined between the San Andreas and Hayward fault zones and is probably directly related in time and position to the deformation along these faults. Possible offset of the Central system by the San Andreas system in the vicinity of Clear Lake and the overprint of the Central system onto the Mendocino and Klamath systems suggest that the chronologic development of the linear systems in the Coast Ranges is—from oldest to youngest—Klamath, Mendocino, Central, and combined San Andreas-Coastal systems.

The Valley system is difficult to fit into the chronologic model presented. It appears to coexist with all of the systems in the southern one-third of the Coast Ranges, the Sacramento Valley, and the Sierran foothills, which suggests that it postdates or is overprinted on the other systems. Alternatively, the imprint of the Valley system on the topography is faint and discontinuous, so it may be that it is a remnant of a long-persisting linear system that predates all the other systems. However, we believe the Valley system represents the youngest of the linear systems because of the fault relations just north of Clear Lake, the over-

print in the Coast Ranges of the Valley system on the San Andreas and Central systems, and the Sierran and Mendocino systems in the Sierra Nevada foothills.

Thus, we conclude that the relative age of the eight linear systems is, from oldest to youngest, Sierran, Klamath, Modoc, Mendocino, Central, San Andreas-Coastal, and Valley systems. The actual geologic ages of the linear systems must depend on detailed field examination of the linear features and their junctions and on the relative ages of the rock units involved.

Although a tentative chronology for the linear systems has been suggested, all of them may have been formed during a relatively short period of time within late Tertiary to Holocene time. Recorded geologic data for northern California, however, suggest that many of the linear features constituting the systems undoubtedly formed during mid- to late Mesozoic time. For example, the Sierran system may have been formed during early to mid-Mesozoic time, but reactivation of some of the linear features within the system may have occurred during and (or) following mid- to late Mesozoic plutonism. The linear systems in the Coast Ranges may be related to late Mesozoic subduction and to late Tertiary transform displacement along the San Andreas fault zone. Recurrent movement along the Mendocino system of linear features and its relation to the other systems suggest that it may have come into existence as early as late Mesozoic time. If so, it forms an important element in the structural framework of northern California.

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LETTERS

L. W. Morley and Sea-Floor Spreading

I have been asked by several geologists for details about the *Saturday Review* article to which I referred in my recent review of Anthony Hallam's book (*Geology*, v. 1, no. 4, 1973, p. 162). A series of articles were included in the magazine under the general heading "Canada's Unappreciated Role as Scientific Innovator." These were written by John Lear, J. Tuzo Wilson, E. T. Degens and D. A. Ross, and Dyson Rose and John Marier. The issue was that of September 2, 1967, p. 45-57.

I recommend the reading of these articles to earth scientists, if only for the partial reproduction (on p. 47 and 48) of L. W. Morley's paper on the interpretation of linear magnetic anomalies, polarity reversals, and his suggested 3- to 5-cm yr⁻¹ separation rate for mid-oceanic ridges. Submitted for publication twice in early 1963, and rejected on both occasions because (in one reviewer's opinion), "Such speculation makes interesting talk at cocktail parties, but is not the sort of thing that ought to be published under serious scientific aegis," the manuscript certainly has substantial historical interest, ranking as probably the most significant paper in the earth sciences to ever be denied publication.

N. D. Watkins

Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

A Vote in Favor

Please accept this vote in favor of *Geology*. The *Bulletin* tells us where we've been, and why; *Geology* provides a glimpse of where we may be going.

Leonard M. Sherman
Little Rock, Arkansas

Birimian Terrane Not Folded During Pan-African Event

In my article, "New K-Ar Age Determinations from the West African Shield in the Niger Republic" (*Geology*, v. 2, no. 1, p. 17-20), I want to point out an error that was introduced during copy editing. I originally wrote (p. 19) "... sedimentary sequence, in this case of later Proterozoic age—in any case considerably younger than the Birimian terrane—which has been strongly folded ... [in the Pan-African event]."

This was changed to "... of later Proterozoic age. In any case, they are considerably younger than the Birimian terrane, which has been strongly folded ... in ... the Pan-African event. ..."

You see? It is not the Birimian terrane which has been folded in the Pan-African event, it is the sequence of later Proterozoic age.

R. O. Brunnschweiler
Bishop Oil & Refining Co.
Niamey, Niger

The editors welcome brief letters on all topics of interest to the geological sciences. Such letters should be typed, double spaced, and addressed to: Henry Spall, The Geological Society of America, 3300 Penrose Place, Boulder, Colorado 80301 U. S. A.

Petersen not Peterson

In the October issue of *Geology* appeared three different contributions by five authors on the subject of "Communities." In all the contributions the name of the great Danish marine biologist and ecologist C.G.J. Petersen was consistently misspelled as Peterson for a total of at least ten times. It is now common, though deplorable, practice to quote references not from the original but from other reference lists, and there is thus a real danger that the great C.G.J. Petersen's name may be ravaged in future publications.

Curt Teichert

Paleontological Institute
University of Kansas
Lawrence, Kansas 66045

A Statement of the Impact of Geodynamics

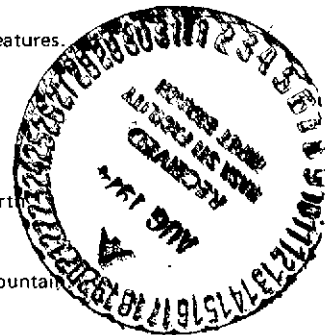
In retrospect some time ago my eye
Saw passing by my favorite grain of dust
In the wind.

It was carried by the rain to the riverbank
And tumbled over rocks
And wandered intimately among the pebbles.
It kissed the slender eel grasses in the marsh
And entered the sea

And studied dark, mysterious anatomy
As a rider on a morsel for a shrimp.
Then crept among diverse microbes
In the sunlit surface layers
And filtered down through salts and darkness
To rest upon the cradle of the mud
Overtaken by worms and crawling creatures.
The grain of dust was covered gently
By companions of the next year.

The grain
In black sediment lay buried and inert
Until eons passed, and forces in the earth
Caused the rearing of that vast plate
Of ocean bottom and basalt
And pushed compacted mud into a mountain

One eroding, stormy day
The grain of dust broke free.
It was my favorite one
From remnants of my grave
I could not see.



Michael L. Healy
Oceanography Section
National Science Foundation
Washington, D.C. 20550

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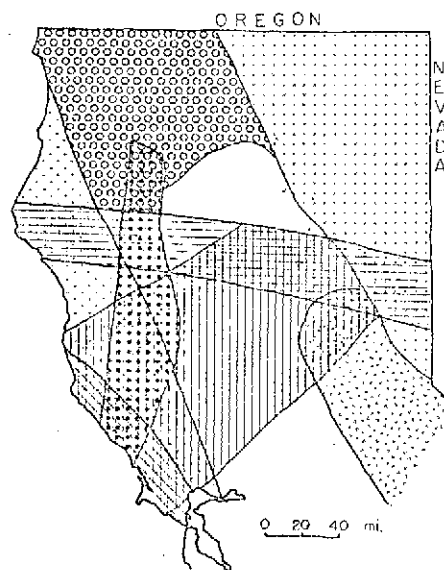


Fig. 5

CAPTIONS FOR ILLUSTRATIONS

Figure 1. Geomorphic regimes, Northern California: C-Coastal; F-Franciscan; M-Metamorphic; K-Klamath Mt.; P-Modoc Plateau; S-Sierra Nevada; B-Basin and Range; G-Great Valley (Sacramento Valley).

Figure 2. ERTS-identified linear features. Solid lines - known faults or linear features believed to be faults; dashed lines - well-defined ERTS-linear features; dotted lines - poorly defined ERTS linear features; lines of open circles - zones of linear features or tonal contrast on ERTS imagery.

Figure 3. Location of linear systems. Interpretation of patterns: + = San Andreas system; NW-SE diagonal lines = Coastal system; dots = Central system; horizontal lines = Mendocino system; open circles = Klamath system; X = Modoc system; V = Sierran system; vertical lines = Valley system.